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# Maine Department of Transportation

# Transportation Research Division

## Technical Memorandum ME 03 - 10

*Experimental Use of Self Consolidating Concrete for Precast Prestressed Box Beams*

*October 2003*

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### Introduction

Self Consolidating Concrete, Self Compacting Concrete, and S.C.C. are terms used to identify a new method of concrete mix design and placement method recently developed in the concrete industry. S.C.C. was first introduced to the concrete industry in the late 1980's, primarily in Europe, and now is beginning to see more use in North America, predominately in precast operations. As of July, 2002 approximately 24 states are involved in the study of this technology. Additionally ASTM Committee C09 on Concrete and Concrete Aggregates formed Subcommittee C09-47 on Self Consolidating Concrete with the goal of adopting this as a future standard. The Precast Concrete Institute (PCI) has also formed a team to study recommendations on the use of SCC in the Precast /Prestressed concrete industry.

As the above photograph shows, SCC is an extremely flowable concrete. SCC is also self leveling and self compacting requiring minimal or no vibration. These mix properties are achieved through a combination of advanced High Range Water Reducers and Viscosity Modifying Admixtures.
As compared to conventional concrete mixes, SCC typically contains a higher cement content and increased percentage of fine aggregate. The workability of SCC is measured by the spread rather than the slump using an inverted slump cone as shown on the cover photo. When determining acceptability of an SCC mix, the diameter of the spread is measured along with the ability of the paste to carry the coarse

aggregate completely to the outer edges of the spread. No concrete should remain visibly higher in the center of the spread and no halo of paste or water should appear around the edges of the spread.

## Problem Statement

The Maine Department of Transportation awarded the contract for the Bridge Replacement Project BR-7574(00)X located in Ogunquit Maine on July 17, 2002. The project was awarded to A & V Construction who then subcontracted the fabrication of the precast prestressed box beams to Strescon Ltd. of St John New Brunswick, Canada.

Placement methods typically used when casting beams of this type are somewhat difficult. The standard method has been to place the bottom slab of the beam first and then insert the box void. Once the box void has been properly positioned it is secured and the remaining reinforcing steel is then placed. This typically took 30 to 45 minutes to complete. The remaining concrete for the sides and top of the beam is then placed. As long as the concrete for the bottom portion of the beam has not begun its initial set this is an acceptable method.

As an alternative to this method, the Department allowed Strescon to use a high slump standard concrete mix design and place the entire box beam in one continuous operation. Although the workability and flow characteristics of this mix were improved, the concern was that this mix would be more likely to segregate under vibration and there would also be a greater chance of large air voids forming under the box voids. Additionally, the area of concern when casting this type of beam is directly under the box void. This area contains 30 tensioned strands which makes it critical that no segregation or lack of consolidation occurs in this area. Due to these concerns the Department decided to investigate the use of SCC for this project.

## Casting of Beams

Casting of the SCC beams for this project began on December 12th, 2002. Present were Michael Redmond of the MDOT Transportation Research Division, William Colburn, the MDOT Quality Assurance Inspector, Denis Dubois, MDOT Fabrication Engineer, Mike O'Connell of Master Builders Chemicals, and Hugo Bursich, Quality Control Manager for Strescon Ltd.

Concrete for the SCC beams was mixed in the same manner as the standard mix used on this project. A three cubic yard central stationary mixer was utilized with buckets on an overhead crane system delivering the concrete to the casting beds. Time from completed mixing to delivery to the forms was typically under one minute unless testing was being performed.

During the casting of these beams one bucket was being used for the SCC beams while the other available bucket was being used for casting of a Dry Cast product ( zero slump mix) in another part of the plant. It is understandable that this practice is a necessity for precast operations when time and labor are involved, but did cause concerns for the Department. Of utmost concern was the time between buckets delivered to the SCC casting beds. As the name suggests, self consolidating concrete does indeed have self compacting properties, unlike any other mix the Department has ever used. It was this mix characteristic that raised concerns with the Department and eventually with the Federal Highway Administration. The method used for these SCC beams was to place an approximate four to five inch layer of SCC along the full length of the beam. This took nearly two full three C.Y. buckets to achieve. As the third bucket was placed over the initial layer it was apparent that the new concrete was flowing over the existing layer and not being consolidated into the layer below. As this was the prescribed method of placing SCC concrete, the Department noted this and allowed the placement to continue as scheduled. On subsequent beams it was decided that any areas which appeared to have consolidated prior to receiving additional SCC concrete would be vibrated to ensure the layers would be consolidated together properly. Additionally, on two occasions during the casting of these first two SCC beams, small pieces of Dry Cast concrete were found in the SCC mix. For the remaining placements, the plant was dedicated to casting SCC beams separate from other work.

## Concrete Test Data

Prior to accepting Self Consolidating Concrete for this project an agreement was made with Strescon Ltd. and Master Builders Admixtures to provide extensive Freeze Thaw Durability Testing. ASTM C666-Procedure A in a 3% Sodium Chloride Solution was performed on numerous samples by Jacques, Whitford and Associates of Dartmouth Nova Scotia. Additionally, comparative testing was performed for Compressive Strength, Rapid Chloride Permeability, and Hardened Air Void Analysis. Results of these tests are provided in the following charts.

**Table.1 Freeze Thaw Durability of Concrete Prisms**
**SCC Mix**

| Air Content | Relative Dynamic Modulus of Elasticity % | Mass % Loss or Gain | Length Change % | Number of Cycles |
|---|---|---|---|---|
| 2.6 % | 38.7 | -2.0 | 0.131 | 252 |
| 2.6 % | 30.8 | -1.86 | 0.165 | 252 |
| 3.4 % | 78.0 | -5.8 | 0.019 | 144 |
| 3.4 % | 32.6 | -5.2 | 0.089 | 144 |
| 4.0 % | 97.2 | -1.7 | 0.007 | 300 |
| 4.0 % | 97.4 | -1.6 | 0.002 | 300 |
| 5.8 % | 99.9 | -0.5 | 0.009 | 300 |
| 5.8 % | 100.7 | -0.2 | 0.011 | 300 |
| 6.0 % | 100.7 | 0 | 0.007 | 300 |
| 6.0 % | 101.1 | 0 | 0.008 | 300 |
| 6.8 % | 98.3 | -1.4 | 0.007 | 300 |
| 6.8 % | 98.9 | -1.7 | 0.004 | 300 |
| 7.2 % | 101.0 | -1.6 | 0.006 | 300 |
| 7.2 % | 98.1 | -2.3 | 0.003 | 300 |
| | **Avg. 99.33** | **-1.1** | **.0064** | |

Freeze Thaw Durability of Concrete Prisms
Standard Mix

| Air Content | Relative Dynamic Modulus of Elasticity % | Mass % Loss or Gain | Length Change % | Number of Cycles |
|---|---|---|---|---|
| No Air | 81.4 | 13.0 | 0.188 | 144 |
| No Air | 81.1 | 11.2 | 0.122 | 144 |
| No Air | 84.6 | -10.5 | 0.057 | 180 |
| No Air | 89.7 | -9.9 | 0.014 | 180 |
| 6.4 % | 97.8 | -3.5 | 0.010 | 300 |
| 6.4 % | 97.2 | -4.6 | 0.012 | 300 |
| 6.8 % | 100.3 | -3.1 | 0.017 | 300 |
| 6.8 % | 95.6 | -4.9 | 0.014 | 300 |
| 7.0 % | 93.0 | -5.3 | 0.013 | 300 |
| 7.0 % | 98.2 | -4.6 | 0.012 | 300 |
| | **Avg. 97.016** | **-4.3** | **0.013** | |

## Table. 2 Air Void System Parameters

| Mix | Points | Length (mm) | Paste % by Vol. | Air % by Vol. | P/A | n 1/mm) | l (mm) | a (1/mm) | L (mm) |
|---|---|---|---|---|---|---|---|---|---|
| 7R | 2116 | 2661 | 33.6 | 6.2 | 5.42 | 0.41 | 0.151 | 26 | 0.182 |
| 11R | 2046 | 2572 | 31.7 | 6.4 | 4.98 | 0.44 | 0.143 | 28 | 0.165 |
| **Average** | **2081** | **2616.5** | **32.65** | **6.3** | **5.2** | **.425** | **.147** | **27** | **.174** |
| 13SCC | 2088 | 2625 | 30.6 | 5.9 | 5.19 | 0.44 | 0.135 | 30 | 0.159 |
| 20SCC | 2054 | 2582 | 34.4 | 5.5 | 6.31 | 0.48 | 0.113 | 35 | 0.145 |
| 24SCC | 2059 | 2588 | 32.9 | 6.8 | 4.84 | 0.49 | 0.137 | 29 | 0.157 |
| 26SCC | 2060 | 2590 | 32.4 | 6.5 | 4.98 | 0.44 | 0.148 | 27 | 0.170 |
| 30SCC | 2109 | 1952 | 34.5 | 4.7 | 7.35 | 0.22 | 0.209 | 19 | 0.288 |
| **Average** | **2074** | **2467.4** | **32.96** | **5.88** | **5.73** | **.414** | **.148** | **28** | **.184** |

## Table 3. ASTM C 1202, Rapid Chloride Permeability

| Sample I.D. | Age ( Days ) | Coulomb Value | Rating |
|---|---|---|---|
| 7R | 138 | 1850 | L |
| 9R | 138 | 2370 | M |
| 11R | 138 | 2130 | M |
| 12R | 139 | 4130 | H |
| | | **Average 2620** | |
| 13SCC | 139 | 1310 | L |
| 20SCC | 139 | 510 | VL |
| 24SCC | 140 | 1410 | L |
| 26SCC | 140 | 1590 | L |
| 30SCC | 150 | 1380 | L |
| 31SCC | 150 | 4370 | H |
| 29SCC | 150 | 2300 | M |
| 29SCC | 150 | 2720 | M |
| | | **Average 1948** | |

## Coulomb Rating Guide

| | |
|---|---|
| **> 4000** | **High (H)** |
| **2000 – 4000** | **Moderate (M)** |
| **1000 – 2000** | **Low (L)** |
| **100 – 1000** | **Very Low (VL)** |
| **< 100** | **Negligible (N)** |

## Table 4. Compressive Strength Results

| | Low | High | Average |
|---|---|---|---|
| **Standard Mix** | 6436 psi | 8605 psi | 7754 psi |
| **SCC Mix** | 7262 psi | 8640 psi | 8055 psi |

## Concrete Mixture Proportions

| Standard Mix | | | SCC Mix | |
|---|---|---|---|---|
| **Material** | | **Amount** | **Material** | **Amount** |
| **Cement** | **Type III** | **760 lbs** | **Type III……… 689 lbs** | |
| **Fly Ash** | | **----------** | **Fly Ash** | **122 lbs** |
| **Sand** | | **1160 lbs** | **Sand………...1316 lbs** | |
| **C. A. ½”** | | **1270 lbs** | **C. A. ½”…….1420 lbs** | |
| **C.A. 3/8”** | | **423 lbs** | | |
| **Water** | | **35.01 gal** | | **36.93 gal** |
| **Air** | | **6.5 +/- 1** | | **7.0 +/- 1.5** |
| **DCI** | | **5.0 Gal.** | | **5.0 Gal.** |
| **Darex II** | | **47.1 oz** | | **12.8 oz** |
| **Daratard 17** | | **50.92 oz** | | **53.7 oz** |
| **WRDA 19** | | **117.04 oz** | | **--------** |
| **Glenium 3200** | | **------------** | | **74.24 oz** |
| **PS-358** | | **------------** | | **23.04 oz** |

| | | | |
|---|---|---|---|
| **W/C Ratio** | **0.38** | | **0.38** |
| **Concrete Unit Weight** | **144.6** | | **142.7** |
| **% Fine Aggregate** | **41 %** | | **48 %** |
| **Slump** | **8”** | **Spread** | **18” – 24”** |

## Evaluation of Test Data

### Freeze Thaw

Freeze Thaw testing was performed on both the SCC mix used during Phase II, and also on the standard mix used for Phase I of this project. Additionally, samples were also cast with no air entrainment, or very minimal air contents. While not a part of this research effort, the question of whether air entrainment is needed in high strength concrete has been discussed within the Department at length. Results of these tests indicate that regardless of the mix type, air entrainment is a necessity.

Examination of the freeze thaw results suggest that both mixes used on this project exhibit excellent Relative Dynamic Modulus of Elasticity with the SCC mix slightly outperforming the standard mix. Likewise, the mass percentage loss and length change percentage also indicate that the SCC mix performed as well or better than the standard mix.

### Air Void Analysis

Samples of both mixes were tested by Master Builders Labs in accordance with ASTM C 457 Standard Test Method for Microscopical Determination of Air Void Content and Parameters of the Air Void System in Hardened Concrete. Test Method B, Modified Point Count. Samples with low air contents are not represented in the table of results provided. Results from the standard mix and the SCC mix indicate both have acceptable air void systems. Very little change was noted on the air void bubble sizes and a slight improvement was realized on the spacing factor which is a critical property related to freeze thaw durability.

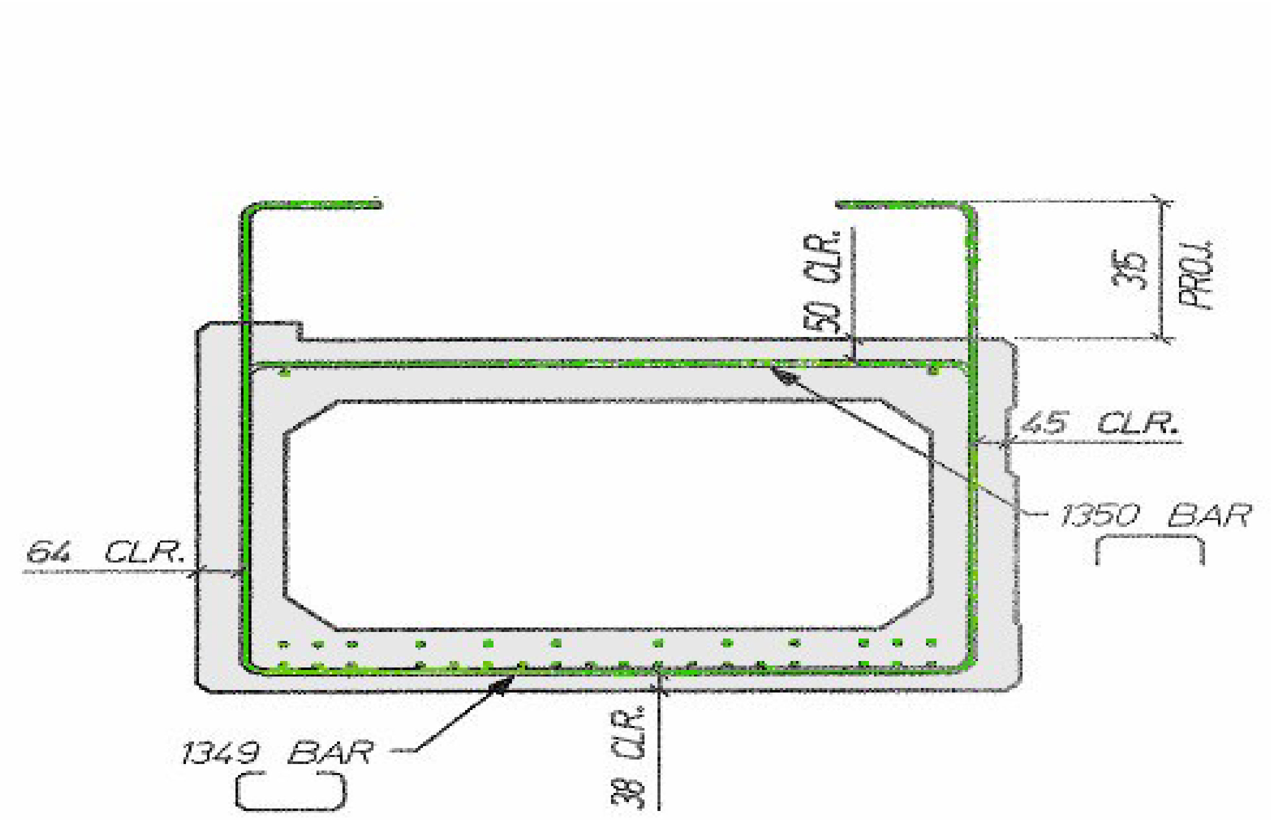
### Chloride Permeability

While not a part of this research effort or a specification on this project, Rapid Chloride Permeability testing was performed for informational purposes only. The results obtained are represented in Table 3 and indicate that both concrete mixes would have met Maine DOT's current specification for Chloride Permeability on Cast in Place Concrete. As can be seen in the Mix Designs used for both Phases of this project, a small amount of Class F Fly Ash was utilized to aide in the flow ability characteristics of the SCC mix. Had a permeability specification been in place for this project, additional pozzolanic materials would likely have been utilized resulting in even lower readings.

### Compressive Strength

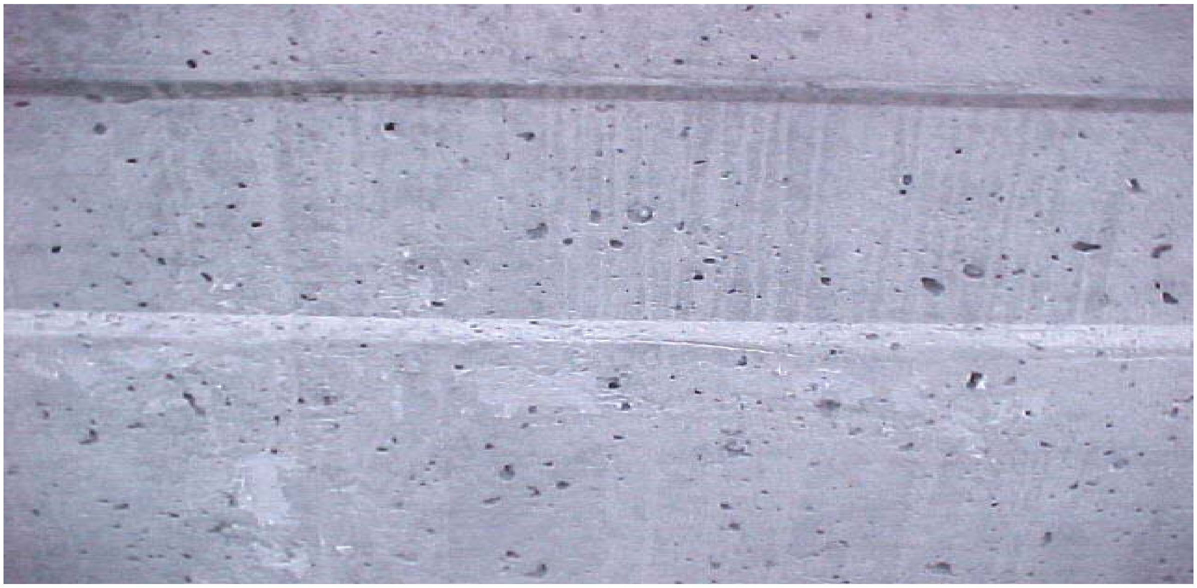
Compressive strength results are represented in Table 4. The high, low, and average strength for each type of mix used is summarized. No appreciable difference was noted between the mixes. The SCC mix did have slightly higher 28 day strengths but also had a higher cementious content and contained Fly Ash as well.

## Photos




*Voided Box Beam Cross Section*

*Aggregate Dispersion with SCC*



*Standard Beam Finish*

*SCC Beam Finish*

*Tight Steel Schedule*


*Strand Detensioning Order*

## Conclusions

From a materials perspective, Self Consolidating Concrete is a product which merits further examination by the Maine DOT. All material properties tested were as good as the Standard Mix or slightly better. Control of the mix by the Strescon Ltd. and Master Builders Quality Control personnel was not an issue on this project.

Placement methods of SCC on this project were a concern. As mentioned earlier in this report, there were concerns related to the compaction and consolidation of subsequent layers or lifts of SCC. Due to Department and Concrete Supplier inexperience with SCC, the structural integrity of the beams required verification by F.H.W.A. Cores examined by the F.H.W.A. Concrete Pavement Team from the Turner Fairbanks Highway Research Center were deemed acceptable and no further testing was performed on the Beams.

## Recommendations

The Department should continue to study and promote the use of SCC for appropriate cast in place bridge and highway applications and should also address the following issues for future SCC projects.

1. When done at a precast plant, no other placements of other types of concrete should be permitted using the same discharge buckets as the SCC.

2. Care should be taken to avoid allowing lifts of SCC to consolidate prior to placement of subsequent lifts of SCC. An ideal scenario would involve the use of redi mixed trucks rather than small quantity buckets.

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